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INVESTIGATION OF RADIATION OF A DENSE PLASMA OBTAINED BY THE DETONATION OF A FINE WIRE IN A VACUUM

A.P. Ryazin and V.S. Shumanov

ABSTRACT: To study the state of matter at a high density and high temperature, a fine wire is detonated in a vacuum, producing a metallic plasma. This paper reports on the investigation of the first stage of detonation, accompanied by a continuous radiation spectrum, in which the maximum energy transferred to the matter of the wire and the spectroscopic characteristics of the radiation are determined.

There has been a recent increase in interest in the investiga- /36* tion of the state of matter at high densities and high temperatures. The electrical detonation of a wire is one of the possible methods for obtaining briefly (0.1-10 μsec) a dense metallic plasma ($\sim 10^{23}$ particles/cm^3), heated to a temperature of up to several tens of thousands of degrees.

Reference [1] shows that in the initial stage of the detonation, commensurate with the resolution time of the system, a sweep of the radiation spectrum of the detonating wire reveals a continuous spectrum, which arises apparently as a result of the radiation of rapidly vaporizing solid and liquid particles of the wire suspended in the plasma and as a result of the radiation of the plasma itself when it is heated to a high temperature. In subsequent experiments, it was shown that the radiation of the continuous spectrum corresponds to the moment in time when the geometric dimensions of the wire have not yet changed significantly. The matter of the wire then scatters in the form of a cylindrical shell; the radiation spectrum at this stage exhibits spectral lines belonging to the atoms and ions of the matter of the wire and the material of the electrode on which the wire is fastened.

This article is devoted to a study of the initial phase of the detonation of the wire; i.e., the stage which is accompanied by a continuous radiation spectrum. We will obtain a radiation spectrum of the detonating wire which is resolved in time and synchronized over time with the electrical characteristics. This provides us with an opportunity to determine the value of the maximum energy (according to the electrical characteristics [2]) transferred to the matter of the wire from the condenser battery until the time of continuous spectrum radiation, in addition to an opportunity to directly investigate the spectroscopic characteristics of the radiation.

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* Numbers in the margin indicate pagination in the foreign text.

Figure 1 shows a schematic of the experimental set-up. The wire is detonated by a battery of condensers which discharge through the wire. The total capacitance of the battery is 40 μF. The discharge contour consists of a battery of condensers (C_1), controlled by an air discharge (1) triggered from the control panel of the ultrahigh speed camera (2); a coaxial conducter (3); the wire under investigation (4); supply busbars. The wire was attached to the axis of the vacuum chamber (5) between the two electrodes made of stainless steel and arranged as clips. The vacuum chamber was evacuated to a pressure of $3 \cdot 10^{-5}$ mm Hg. /37

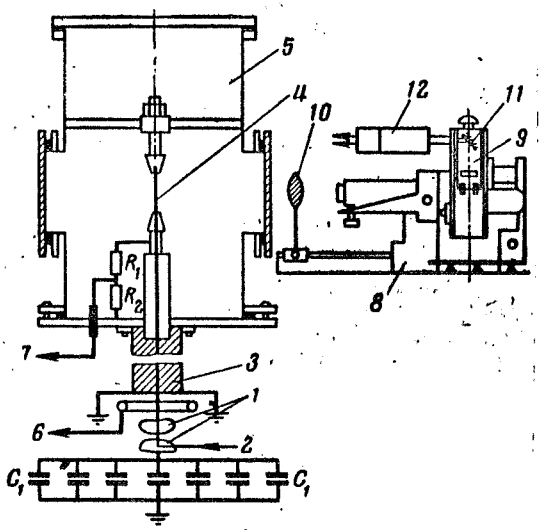


Fig. 1. Schematic of the Experimental Set-Up.

The discharge current across the wire was measured by a Rogowski integrating loop (6), and the voltage on the wire was measured by a low-resistance voltage divider (7) located in the vacuum chamber. Signals from the Rogowski loop and the voltage divider passed to the plates of a twin-beam pulse oscillograph (OK-17 or OK-21). The initial voltage on the battery of condensers was 30 kV. The discharge period was 46 μsec. The maximum discharge current was 150 kA; the experiments were conducted using a copper wire 31 mm in diameter and 100 mm long. The radiation spectrum (which was resolved over time) of the detonating wire (Fig. 2) was obtained using an ISP-51 spectrograph (8) combined with the ultrahigh-speed camera (USC) (9). The image of the wire (4) through the side window of the chamber was focused by a lens (10) on the slit of the spectrograph.

A Hartman diaphragm located in front of the slit defined the image of the central part of the wire (the part of the diaphragm with $\delta \approx 0.65$ mm was used). Light rays passed through the scattering system of the spectrograph and were focused by an adapter lens (Jupiter 3; $f = 50$ mm) in the focal plane of the optical system of the ultrahigh-speed camera. Then the radiation spectrum of the detonating wire, limited by the height of the Hartman diaphragm, was focused by the optical system of the USC onto film in the USC so that the axis of the spectral wavelengths λ was perpendicular to the direction of motion of the mirror sweep. Thus, each section of the spectrum and the spectral lines were rotated in time (the axis of rotation of the USC mirror was located in the horizontal plane). Time resolution of the system when the USC mirror was rotating at a rate of 75 thousand rpm was 0.08 μsec. To synchronize the sweep of the radiation spectrum with the discharge current across the wire, in front of the photographic film we placed a small mirror (11), the light from which passed along a light conductor to an FEU-19 photomultiplier (12). The signal from the photomultiplier and the

signal from the Rogowski loop arrived at the OK-17 m oscillograph simultaneously. Since the position of the mirror in front of the photographic film is known, on the basis of the oscillograms (Fig. 3) we can determine what moment in time relative to the beginning of detonation process corresponds to which sections on the sweep of the radiation spectrum.

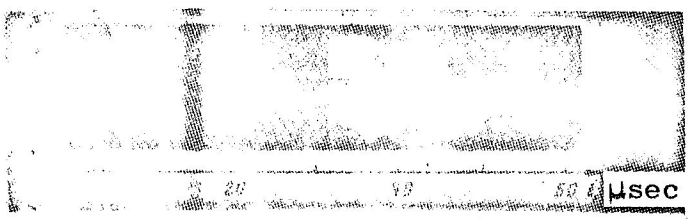
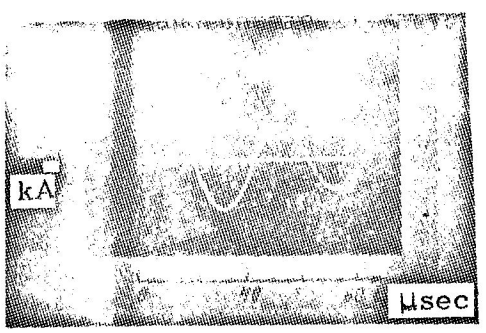


Fig. 2. Time Sweep of the Radiation Spectrum of the Detonating Wire.

Figure 4 shows the oscillograms of discharge current and voltage on the wire, according to which, as demonstrated in [2], we can trace the phase transformations in the material and also the change in the resistance of the wire over time. /38 At the moment of time which corresponds to the maximum voltage value, the material of the wire has the minimum conductivity; i.e., it is in a vapor-like state. It is near this moment in time when we observe a continuous radiation spectrum lasting 0.2-0.3 μsec (Figs. 2 and 3).

On the basis of the current and voltage oscillograms we com-



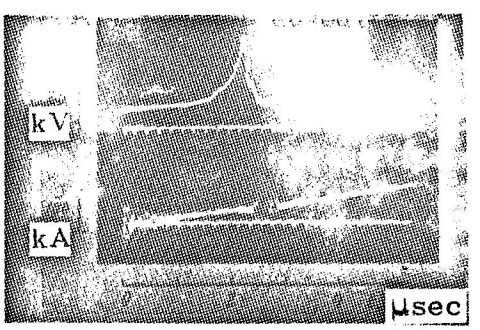


Fig. 3. Oscillograms of the Synchronization Signal from the Photomultiplier and the Discharge Current across the Wire I.

Fig. 4. Oscillograms of the Voltage U on the Wire and the Discharge Current I across the Wire. The Time Is Calibrated Every 0.2 μsec.

puted the value of the maximum energy E transferred to the wire from the battery of condensers before the continuous spectrum of radiation. The value of E is equal to 362 J. There is enough of this energy for almost total vaporization of the matter of the wire.

According to the relative energy distribution in the continuous radiation spectrum, we estimated the temperature of the material of the wire at this stage of detonation. To do this, in the

spectral range 4000-6000 Å, we recorded the blackenings and the radiation spectrum of the detonating wire, expanded over time. As a standard light source we used a tungsten filament lamp (incandescence: Si 8-200). The exposure time was approximately 10^{-3} sec provided by a slit shutter. The slit of the spectrograph was varied from 40 to 400 μ. The spectrograms obtained were interpreted by heterochromatic photometry.

In Figure 5, which depicts the relative energy distribution as a function of wavelength, the points show the results of the interpretation of the spectrograms obtained in a number of experiments under identical initial conditions. The line shows the energy distribution in the radiation spectrum of a black body for a temperature of 50,000°K. We should note that at such high temperatures in the visible range of the spectrum the curve of the relative energy distribution of black-body radiation varies only slightly with temperature, and the error in measuring the intensity distribution of the radiation of the object under examination by heterochromatic photometry is 20%.

Thus, in the given case we can use this method only for an approximate estimate of the value of the temperature of the detonating wire [3]. By comparing the measured values of the relative energy distribution of the radiation of the detonating wire with the relative energy distribution of black-body radiation at various temperatures, we can conclude that the temperature of the material of the wire at the given stage of the detonation is 30-40 thousand°K. This indicates the possibility of nonuniform energy release in the volume of the wire, since the energy transferred to the wire prior to this moment in time is clearly not sufficient to heat the entire mass of the wire to such temperatures. /39

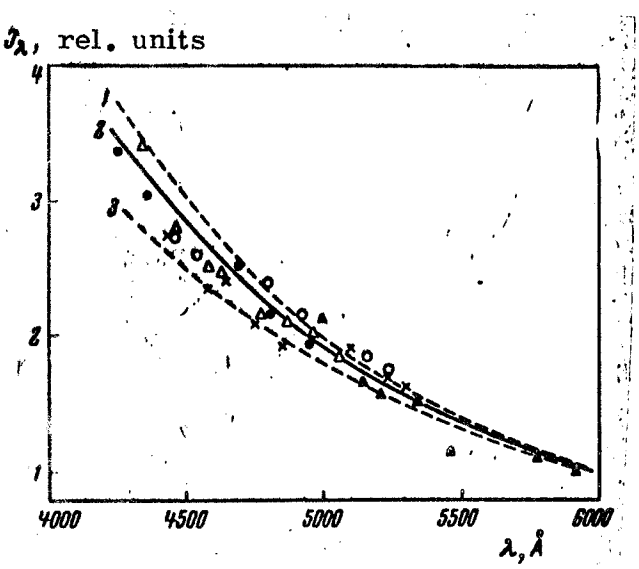


Fig. 5. Energy Distribution in the Continuous Radiation Spectrum of the Detonating Wire: (1) 100,000°K; (2) 50,000°K; (3) 25,000°K.

We now face the obvious problem of further studies of the relative energy distribution in the continuous spectrum for a wider interval of wavelengths; in particular, in the shortwave range of the spectrum and measurements of the absolute intensity of the radiation, which may help to answer the question on whether the radiation of the wire at a given stage of the detonation is equilibrium or originates due to an accelerated mechanism which, at high voltages in the discharge interval and low densities of the matter around the wire, is quite probable.

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